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Claims

[c1] 1.A well logging apparatus for conducting measurements in a borehole environment surrounding a borehole that traverses a subsurface formation, said apparatus comprising;

an elongated conductive mandrel having a longitudinal axis;

an antenna array positioned about said mandrel and including a transmitter for transmitting electromagnetic energy into the formation;

a sleeve positioned about said antenna array, said sleeve having an outer surface positioned for exposure to the borehole environment and an inner surface positioned radially inward of said outer surface;

a first electrode having an outer end and an inner end positioned radially inward of said outer end, said first electrode being supported on said sleeve such that said outer end is exposed on said outer surface of said sleeve for conductive contact with an adjacent conductive borehole environment; and

a second electrode having an outer end and an inner end positioned radially inward of said outer end, said second electrode being supported on said sleeve such that said

outer end is exposed on said outer surface of said sleeve for conductive contact with the adjacent conductive borehole environment, said first and second electrodes being spaced longitudinally apart such that said transmitter is positioned longitudinally therebetween; and wherein said first and second electrodes are conductively interconnected with said mandrel such that when said well logging apparatus is operated in a borehole environment having borehole currents therein, one or more current path loops are provided for shorting borehole currents, said current path loops including a first conductive path between the conductive borehole environment, said first electrode, and said mandrel, and a second conductive path between said conductive borehole environment, said second electrode, and said mandrel.

[c2] 2.The well logging apparatus of Claim 1, wherein each said electrode is a component separate from, and movable relative to, said mandrel.

[c3] 3.The well logging apparatus of Claim 2, further comprising a first conductive connection and a second conductive connection, each said conductive connection being disposed between one of said electrodes and said mandrel to conductively interconnect said electrode with said mandrel, each said conductive connection being a component separate from said electrode and said man-

drel.

[c4] 4.The well logging apparatus of Claim 1, further comprising:

a first set of electrodes supported on said sleeve above said transmitter and azimuthally spaced apart about said sleeve, said first set including said first electrode, wherein each of said electrodes of said first set are conductively interconnected with said mandrel;

a second set of electrodes positioned below said transmitter and azimuthally spaced apart about said sleeve, said second set including said second electrode, wherein each of said electrodes of said second set are conductively interconnected with said mandrel; and

wherein each of said electrodes of said first and second sets has an outer end and an inner end positioned radially inward of said outer end, each said electrode being supported on said sleeve such that said outer end of each said electrode is exposed on said outer surface of said sleeve for conductive contact with the adjacent conductive borehole environment, and such that said current path loops include current path loops between the conductive borehole environment, an electrode of the first set of electrodes, the mandrel, an electrode of the second set of electrodes, and the conductive borehole environment.

[c5] 5.The well logging apparatus of Claim 1, wherein said sleeve is made of a non-conductive material, said sleeve material having a plurality of channels each radially extending therethrough for supporting one of said electrodes.

[c6] 6. The well logging apparatus of Claim 5, wherein said channel is sized to provide a gap between said sleeve and said electrode, said well logging apparatus further comprising a flexible, non-conductive material situated in said gap.

[c7] 7.The well logging apparatus of Claim 6, wherein said first and second electrodes each has a first section including said outer end and a second section positioned radially inward of said first section, said second section having a width or diameter substantially less than a corresponding width or diameter of said outer end.

[c8] 8.The well logging apparatus of Claim 7, wherein said flexible, non-conductive material is a rubber sleeve positioned about said electrode.

[c9] 9.The well logging apparatus of Claim 1, wherein said electrode is positioned in said channel such that said outer end is spaced radially inwardly of said outer surface of said sleeve.

[c10] 10.The well logging apparatus of Claim 1, wherein said outer end is provided by a metallic plate having slots provided thereon, said slots forming a conductive path across said plate.

[c11] 11.The well logging apparatus of Claim 10, wherein said slots form a plurality of interconnected narrow sections defining a narrow continuous conductive path across said plate.

[c12] 12.The well logging apparatus of Claim 11, wherein said narrow sections are disposed in generally parallel relation.

[c13] 13.The well logging apparatus of Claim 1, wherein said transmitter has a transversely eccentered dipole.

[c14] 14.The well logging apparatus of Claim 1, wherein said outer end has an exposed surface area substantially larger than a radially inwardly facing surface area of said inner end, and said electrode having a base section positioned between said outer end and said inner end, said base section having a width or diameter that is less than a width or diameter of said exposed surface area, and wherein said electrode further includes a flexible non-conductive, sleeve positioned about said base section.

[c15] 15.The well logging apparatus of Claim 1, wherein said current path loops include a current path loop between the conductive borehole environment, said first electrode, said mandrel, said second electrode, and said conductive borehole environment.

[c16] 16.The well logging apparatus of Claim 1, wherein said antenna array further includes a receiver for receiving a response signal from the formation, said receiver being positioned about said mandrel.

[c17] 17.In a well logging apparatus for conducting measurements in a borehole environment surrounding a subsurface borehole that traverses a subsurface formation, the apparatus including an elongated conductive mandrel and triaxial antenna array positioned about the mandrel and the antenna array further including a transmitter for transmitting electromagnetic energy, a sleeve assembly comprising:

a non-conductive sleeve positioned about the antenna array and about a longitudinal axis the well logging apparatus, said sleeve having an outer surface positioned for exposure to the borehole environment and an inner surface positioned radially inward of said outer surface;

a first set of electrodes supported on said sleeve longitudinally above the transmitter and azimuthally spaced apart about said sleeve, said electrodes of said first set

being conductively interconnected with the mandrel; and a second set of electrodes positioned longitudinally below said transmitter and azimuthally spaced apart about said sleeve, said electrodes of said second set being conductively interconnected with the mandrel; and wherein each of said electrodes of said first and second sets has an outer end and an inner end positioned radially inward of said outer end, said outer end of said electrode being exposed on said outer surface of said sleeve for conductive contact with an adjacent conductive borehole environment, such that when said well logging apparatus is operated in a borehole environment having borehole currents therein, current path loops are provided for shorting borehole currents, said current path loops including current path loops between the conductive borehole environment, the first set of electrodes, the mandrel, the second set of electrodes, and the conductive borehole environment.

[c18] 18.The sleeve assembly of Claim 17, further comprising a first set of conductive connections and a second set of conductive connections, each said conductive connection being disposed between one of said electrodes and said mandrel to conductively interconnect said electrode with said mandrel, such that said current path loops include a radially conductive path between the conductive bore-

hole environment, said electrode, said conductive connection, and the mandrel, and wherein said conductive connection is separate from and movable relative to said electrode and the mandrel.

[c19] 19.The sleeve assembly of Claim 17, further comprising a plurality of channels radially extending between said outer surface and said inner surface of said sleeve, each said electrode being situated in said channel.

[c20] 20.The sleeve assembly of Claim 19, wherein said channels are sized to provide a gap between said sleeve and said electrode, said sleeve assembly further comprising a flexible, non-conductive material situated in said gap between said electrode and said sleeve.

[c21] 21.The sleeve assembly of Claim 20, wherein said electrode includes a base section radially extending from said outer end, said base section having a width or diameter substantially reduced from a corresponding width or diameter of said outer end.

[c22] 22.The sleeve assembly of Claim 20, wherein said electrode is positioned in said channel such that said outer end is spaced radially inwardly of said outer surface of said sleeve.

[c23] 23.The sleeve assembly of Claim 17, wherein said outer

end is provided by a slotted metallic plate defining a narrow, continuous conductive path.

[c24] 24.The sleeve assembly of Claim 23, wherein said electrode further includes a base section extending radially inwardly from said metallic plate, said base section having a lateral cross-sectional area that is substantially less than an exposed surface area of said metallic plate.

[c25] 25.The sleeve assembly of Claim 23, wherein said metallic plate is slotted to form a plurality of interconnected narrow sections defining said continuous conductive path.

[c26] 26.A method of reducing borehole current effects on measurements conducted with a well logging apparatus in a conductive borehole environment surrounding a borehole that traverses a subsurface formation, wherein borehole currents are generated in the borehole environment adjacent the well logging apparatus, said method comprising the steps of:
providing a well logging apparatus having an elongated conductive mandrel with a longitudinal axis, an antenna array positioned about the mandrel and including a transmitter for transmitting electromagnetic energy and a receiver for receiving a response signal from the formation, a sleeve positioned about the antenna array, the

sleeve having an outer surface positioned for exposure to the borehole environment and an inner surface positioned radially inward of the outer surface;

supporting an upper set of electrodes in the sleeve at a position longitudinally above the transmitter and a lower set of electrodes in the sleeve at a position longitudinally below the transmitter, whereby electrodes of the first and second sets radially extends between the outer surface of the sleeve and the inner surface, such that the upper set of electrodes and the lower set of electrodes are conductively interconnected through the mandrel;

positioning the well logging apparatus in the borehole such that the outer surfaces of the electrodes are exposed to the conductive borehole environment; and

operating the well logging apparatus to transmit electromagnetic energy into the formation, whereby borehole currents are generated in the conductive borehole environment;

directing borehole currents into current path loops between electrodes of the first set of electrodes, the mandrel, electrodes of the second set of electrodes, and the conductive borehole environment thereby shorting the borehole currents and reducing the borehole current effects on the receiver.

[c27] 27.The method of Claim 26, wherein said step of provid-

ing upper and lower sets of electrodes includes providing an upper set of electrodes that are azimuthally spaced apart about said sleeve, and a lower set of electrodes that are azimuthally spaced apart about said sleeve.

[c28] 28.The method of Claim 26, wherein said step of positioning the well logging apparatus includes positioning the well logging apparatus such that the transmitter has a transversely eccentered dipole.

[c29] 29.The method of Claim 26, wherein said step of directing borehole currents includes directing the borehole currents from the conductive borehole environment radially through the electrodes and to the mandrel.

[c30] 30.The method of Claim 26, wherein said step of directing borehole currents includes directing the borehole current into a current path loop that includes a conductive path between the conductive borehole environment, one of the lower set of electrodes, the mandrel, a second one of the lower set of electrodes, and the conductive borehole environment.